MOP-6802

TITLE: PRE-DEPLOYMENT AND QC CHECKS FOR ORS FACILITY INSTRUMENTATION

SCOPE: Describes the pre-deployment and QC checks to be performed on the Generators, Retroflectors, Scanners, Optical Anemometer, Meteorological Station, Topcon Theodolite, and Lowrance GPS, as well as the pre-deployment DQIs for the OP-FTIR [OP-FTIR Single Beam Ratio Test, Baseline Stability Test, Signal to Noise Test/Noise Equivalent Absorbance (NEA), ZPD Stability, Saturation of Instrument (Detector Nonlinearity), Random Baseline Noise, and Stray Light] and the OP-TDLAS (Instrument Operation Check).

PURPOSE: To provide the procedures and frequency for pre-deployment and QC checks for ORS Facility instrumentation before the start of the field campaign, as well as the potential for corrective action.

1.0 PROCEDURE

Pre-deployment and QC checks are performed by field personnel on the EPA campus, prior to deployment to the field. The results of these checks and any corrective action(s) taken should be documented in a numbered project notebook, which is in the custody of the field team leader. All maintenance documentation should be recorded in equipment logs, which are then stored in the Wells Cargo Trailer.

1.1 Generators

Oil level should be checked in each generator. If low, bring the oil up to the mark. Each generator should be started, and any difficulties encountered should be corrected.

1.2 Retroflectors

The test plan should be checked for the number of mirrors required by the experiment, and sufficient mirrors should be located. The number of mirrors with dovetail mounts should be checked versus the number needed for mounting on tripods. Check the rigidity of the tripod heads and mirrors mounts. Tighten, or otherwise correct, loose mounts or fittings. Check the surface cleanliness of each mirror. If significant dirt is noted, clean by the approved procedure.

1.3 OP-FTIR Pre-Deployment DQIs

To identify potential problems in advance of deployment, instruments are generally set up a week or two before going out to the field. While no formal calibration checks are carried out, DQI tests (OP-FTIR Single Beam Ratio Test, Baseline Stability Test, Signal to Noise Test/Noise Equivalent

Absorbance (NEA), ZPD Stability, Saturation of Instrument (Detector Nonlinearity), Random Baseline Noise, and Stray Light) are performed. For many of the problems identified by these QC checks, it is possible to take corrective action to improve instrument performance prior to deployment. Some examples of correctable problems include re-alignment of the instrument mirrors to improve signal strength, or manipulating the power source to reduce the amount of electronic noise. Some of the problems identified may not affect data quality, but indicate a potential long-term problem with the instrument which should be corrected by an instrument specialist after the field campaign has been completed. An example of this would be a major degradation of signal strength that could be corrected by re-aligning the internal optics of the instrument.

The following tests are applicable to both monostatic and bistatic systems, manufactured by Midac, IMACC, RAM2000, or similar vendors. When these tests are performed on instruments that have a different range of resolutions (e.g., ETG's system operates at 1 cm^{-1}, whereas Optra's system operates at 4 or 8 cm^{-1}), the procedures should be adjusted to accommodate these ranges. For instance, if the highest resolution of the system is 4 cm^{-1}, then all procedures that specify 0.5 cm^{-1} should be changed to 4 cm^{-1}.

When performing these tests on a bistatic instrument, analog-to-digital (A/D) overflow may occur unless mesh screens or strips of tape are used to control the light throughput. When using tape to attenuate the beam, the tape should be applied at the circular aperture of the telescope along a chord that intersects the center of the aperture (center of the secondary mirror). More information on these checks can be found in the US EPA *Compendium Method TO-16: Long-Path Open-Path Fourier Transform Infrared Monitoring of Atmospheric Gases,*[a] and the *ASTM Standard Practice E1982-98* document.[b]

1.3.1 OP-FTIR Single Beam Ratio Test

The Single Beam Ratio Test is a fast and easy check on whether the infrared beam is properly aligned through the Michaelson interferometer. Poor alignment in the interferometer results in considerable cancellation of the high-frequency portion of the infrared spectrum.

Align the instrument on the shortest pathlength to be used in the field campaign. Collect an interferogram at 8.0 cm^{-1} resolution, with a 10-second sample time. The instrument gain should be set at 1.0. Convert the interferogram to a single beam spectrum. Compare the maximum signal value (Y-axis value) of the spectrum at or near 2000 cm^{-1} to the signal value at or near 4000 cm^{-1}. Record the two signal values and the ratio of the value at 4000 cm^{-1} to the value at 2000 cm^{-1}. The signal value at 4000 cm^{-1} should be greater than 20% of the signal value at the 2000 cm^{-1} wavenumber.

1.3.2 Baseline Stability Test

1. Set the system parameters to:
    - Resolution: 4 cm^{-1}
    - Sample Time: 5 seconds

- Gain: 1
- Delay between samples: 0
- Number of samples: 12
- File Save: Interferogram

2. Collect a background spectrum.
3. Collect the designated number of samples.
4. Convert the samples to absorbance spectra.
5. Open all of the sample spectra in *Grams* or *Omnic* software; select the “Overlay Spectra” display option.

Record the total drift, in Absorbance Units (AU). The total drift of the baselines of all overlaid spectra should not exceed ± 0.002 AU at ~1000 cm^{-1}.

1.3.3 Signal to Noise Test - Noise Equivalent Absorbance (NEA)

The Noise Equivalent Absorbance (NEA) is a measure of the instrument noise and is generally used as an instrument quality metric. This test is performed over a very short path to eliminate the contribution of atmospheric sources to the noise. The mirror or bistatic infrared source is placed as close to the OP-FTIR telescope as possible, without touching the telescope. This setup is referred to as “Zero Path.” The mirror array should be at least as large as the OP-FTIR primary mirror and set up so that part of the array is in front of every portion of the primary mirror. Set the gain to 1 and collect five, one-minute interferograms at 0.5 cm^{-1} resolution (for lower-resolution instruments, set the resolution to the maximum resolution used in the field and expand the three spectral regions (listed below) by a factor of the maximum instrument resolution divided by 0.5. This will ensure that the NEA determination is performed over 80 data points. If A/D overflow or detector saturation occurs, attenuate the beam using either wire meshes or tape strips (to block part of the beam). Create four differential absorbance spectra from the four interferograms by using the first interferogram as the background to process the second interferogram, the second to process the third, the third to process the fourth, and the fourth to process the fifth.

For each of the four differential absorbance spectra, record the root-mean-square (rms) noise in the following three spectral regions:

1. 978 to 998 cm^{-1}
2. 2500 to 2520 cm^{-1}
3. 4390 to 4410 cm^{-1}

Each OP-FTIR sensor will have its own NEA specification. Because different applications may have different performance requirements, there is no specific pass or fail criterion for the NEA test. However, if the NEA determinations in regions 1 or 2 are greater than 0.001 AU, the project leader should be advised of the NEA test results, so that they may determine if the signal-to-noise ratio is sufficient for the intended application. Region 3 is only important if analysis is to be performed on absorption bands at wavenumbers higher than 4000 cm^{-1}. Hydrogen fluoride is generally the only chemical species that is analyzed at wavenumbers higher than 4000 cm^{-1}. The noise specification for Region 3 is a factor of four higher than for the other regions. Poor NEA determinations indicate that maintenance of the instrument, with respect to cleaning and possibly alignment, should be scheduled as soon as possible.

The five Zero-Path interferograms should be saved for possible use in quality testing synthetic backgrounds ,or to replace synthetic backgrounds as Zero-Path backgrounds.

1.3.4 ZPD Stability

Perform the ZPD Stability test only after the system has been powered for a minimum of three hours and the detector has been chilled for a minimum of one hour. Using appropriate software,* put the system into the "Alignment" mode (set to 8 cm^{-1} resolution), and observe the Center Burst position (located on the X-axis) for two minutes. The position of the Center Burst should be constant over the two-minute period. Note whether any shifts in the position occur.

1.3.5 Saturation of Instrument (Detector Nonlinearity)

There are two main reasons why the OP-FTIR sensor may respond nonlinearly to changes in the infrared intensity:

The electronic gain may be set too high, resulting in the A/D converter becoming saturated. When this occurs, the peak signal of the centerburst of the interferogram will be clipped. The adjustment of the electronic gain is set by the pot(s) on the detector preamplifier board. This is only a problem when the A/D is saturated at low signal levels, and where reducing the signal will result in failure of the Signal to Noise Test in Section 1.3.3. In this case, the gain should be reduced by adjusting the pot(s) on the detector preamplifier board, following the manufacturers' instructions.

There may be too much infrared light incident on the detector, resulting in saturation of the detector (the detector no longer provides a linear response to changes in the infrared signal).

To test for detector nonlinearity, set up a mirror at the shortest path length to be used in the study. Align the instrument on the mirror and collect an interferogram for 1 minute at 0.5 cm^{-1} resolution. The software gain of the instrument should be set at 1.0.** Convert the interferogram to a single beam spectrum. Inspect the single beam spectrum in the wavenumber region below 700 cm-1 .***

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* *Grams* or *AutoQuant* for Midac, *RMMSoft* for RAM2000, and *Omnic* for IMACC.

** The software gain is the gain that is adjusted in the data acquisition software (with integers from the binary series – 1, 2, 4, 8, etc.) and should not to be confused with the electronic gain.

*** For paths shorter than 25 meters (one-way), the response will not be flat. For the shorter paths, the signal strengths should be close to zero at 668 cm^{-1} and 2360 cm^{-1}. If any part of the single beam spectrum has signal values that are negative or less than the values at 668 cm^{-1} and 2360 cm^{-1}, the detector is saturated

For pathlengths greater than 25 meters, the instrument response should be flat at the zero-signal level. If not, this indicates that the detector is saturated. Block part of the mirror from the infrared beam with a strip of tape and repeat the test. If saturation continues to occur, add another strip of tape and repeat the test. Repeat these steps until detector saturation is eliminated. Then repeat this procedure for the next closest path until detector saturation is eliminated. Continue this procedure with each subsequently longer path until a tested path results in no saturation without using tape. Longer paths need not be tested unless the corresponding peak-to-peak voltage is larger than the shortest path that passed the test.

1.3.6 Random Baseline Noise

To assess the random baseline noise of the system, align the instrument on a mirror to be used in the field campaign. Collect two single beam spectra sequentially at 0.5 cm^{-1} for 10 seconds. The gain of the instrument should be set at 1.0. Analysis of the random baseline noise will be done after the field study is completed.

1.3.7 Stray Light

Some monostatic systems[****] will detect a significant level of the outgoing infrared light that is scattered off of surfaces, inside the instrument enclosure, that are in the detector's field of view. Since this scattered light has not traversed the measured path, it contains none of the absorption bands of the species that are being measured. If the level of the scattered light is more than a few percent of the returned-beam signal, a significant negative bias in the concentration determinations will occur. For instruments operating to specifications, this problem is most apparent in the Midac, occurs to a much lesser extent in the RAM2000, and is generally undetectable in the IMACC. Indeed, the stray light in the IMACC is so low that the center-burst signal is lower than the noise. Under these conditions, collection of stray-light interferograms is not possible.

The test for stray light is a two-step process in which the first step will determine if any stray light is detected. If the first step detects stray light, then the second step will quantify the stray-light level and provide, if necessary, a relatively low-noise spectrum to correct the measured spectra for stray light. Once the stray light intensity is known and measured, it should not change unless some component of the optical system is changed.

1. In alignment mode, align the beam to a mirror. After observing a definite return interferogram signal, jog the OP-FTIR far from the mirror and observe if an interferogram signal is detected. If the signal disappears, the instrument does not experience stray light and no further test will be required. If an interferogram is detected, go on to Step 2.
2. While the instrument is still positioned away from the mirror, set the resolution to 8.0 cm^{-1} and the gain to a value that maximizes the peak-to-peak signal without A/D overflow.

**** Bistatic systems do not experience stray light, but they are subjected to ambient radiation, which has a similar effect on the concentration measurements.

Collect 16, one-minute samples. Convert the 16 interferograms to 16 single-beam spectra. Co-add the 16 one-minute, single-beam spectra to produce one 16-minute, averaged single beam.

During the data analysis phase of the field project, the signal level of the co-added 16-minute single-beam stray light spectrum will be compared to the level of the measurements at 1000 cm^{-1} and recorded for the report. If the stray light level is significant (> 5 percent), the measurement results can be corrected by one of two different methods:

a. The 16-minute single-beam spectrum is interpolated to match the data points of the measured spectra. The interpolated stray-light single beam is then subtracted from the single beams that were obtained by performing a Fourier transform of the measurement interferograms. Quantitative analysis is then performed on the resulting processed single beam spectra.

b. The field-measurement spectra are first analyzed to obtain concentrations. The signal-strength of the uncorrected single beams are listed along with the corresponding peak absorptions and concentrations. The concentrations are corrected for the stray light using information on the stray light single-beam signal and the returned beam signal at 1000 cm^{-1}, and the peak absorption of the measured chemical absorption band.

The second method may be preferred if the first method produces too much noise.

1.4 TDLAS Pre-Deployment DQIs

1.4.1 Instrument Operation Check

The TDLAS is unlike the OP-FTIR in that the only QC check necessary before field deployment is ensuring that the instrument is operational. After the instrument is turned on, absorption peaks should become visible on the screen. No warm-up period is required. There are two absorption peaks visible in the software, sample and reference. The sample peak is only visible when the gas species selected is present within the open path. The reference peak is visible all the time, even without a telescope connected. This is a commercial piece of equipment intended for data collection. The data stored is in path average concentrations (ppm) identified by the sample gas and telescope selected.

1.4.2 Calibration Check

As a DQI check, the calibration of the Unisearch model CXL840 is verified through manual insertion of 10 cm-long by 1 cm-diameter cylindrical gas cells containing known concentrations of the species of interest into the optical beam path during measurement. The instrument provides the gas cell insertion slot prior to the telescope multiplexing section of the hardware controller allowing for efficient calibration checks on all utilized optical paths. The absorption signal generated by the gas cell is additive to the field absorption signal for that optical path. For the species under test, the measured path-integrated concentration (PIC) will increase by an amount proportional to the concentration of the gas contained in the cell. The response calibration factors for individual species are verified through comparison of the actual and expected concentration changes with the calibration cell in place. The accuracy DQI for the calibration check is passed when the actual concentration with cell insertion is within +/- 10 of expected value with a precision of +/- 5% based on 5 consecutive readings. More information can be found in Reference c.

1.5 Scanners

The following procedure pertains to all scanners that may be used in the field, including those manufactured by Yuasa and Orbit. The scanners are tested along with the monostatic instrument a week or two before deployment to the field. The OP-FTIR is put into alignment mode and manually aimed at each of three mirrors until return signals are recorded. The positions of the mirrors should be selected to include both horizontal and vertical movements. The coordinates corresponding to these signals are then entered into the scanner controller and the positions are checked manually to confirm that the OP-FTIR is still aligned with each of the mirrors.

1.6 Optical Anemometer

A week or two before deployment, the optical anemometer is aligned and the intensity of the return signal is checked.

1.7 The Meteorological Station

The meteorological head DQIs are checked annually as part of the routine calibration procedure performed by the APPCD Metrology Lab. Before deployment to the field, the user should verify the calibration date of the instrument by referencing the calibration sticker. If the date indicates the instrument is in need of calibration, it should be returned to the APPCD Metrology Laboratory before deployment to the field.

1.7.1 Two Head Comparison

The precision and accuracy of the heads are assessed by placing the two heads side-by side, and collecting data for 10 minutes. The average difference and the standard deviation of the difference in wind speed and wind direction measurements between the two heads are calculated. The accuracy of the heads is assessed by the calculated average difference of the parameter being measured. The precision of the heads is assessed by the calculated standard deviation. Both the accuracy and precision must be within ±1 m/s for wind speed and ±10º for wind direction. The results of the comparison should be recorded in a laboratory notebook maintained by the Field Team Leader.

1.7.2 Reasonableness Checks

A couple of reasonableness checks must be performed on the measured wind direction data prior to deployment to the field. While data collection is occurring, the measured wind direction should be compared to the forecasted wind direction for that particular day. Another reasonableness check that must be completed involves manually setting the vane on the meteorological heads to magnetic north (this is done with a hand held compass). The observed wind direction during this test should be very close to 360º/0º.

1.8 Topcon Theodolite

Each theodolite is calibrated by the manufacturer prior to being received by the EPA. Calibration checks are not performed on this instrument before each field campaign. However, calibration checks will be performed annually on the distance and angle measurements by ARCADIS field personnel. Additionally, there are several internal checks in the theodolite software that prevent data collection from occurring if the instrument is not properly aligned on the object being measured, or if the instrument has not been balanced correctly. When this occurs, it is necessary to re-initialize the instrument to collect data.

1.8.1 Assessment of Distance Measurement

The distance measurement calibration test is performed by measuring a set distance (e.g., 50 meters) with a tape measure. This distance is then measured using the theodolite. The measurement is performed at least three times, and the results of the measurements are recorded in a laboratory notebook maintained by the Field Team Leader. The accuracy of the measurement is assessed by comparing the distance measured with the tape measure to the distances measured with the theodolite. The precision of the measurement is assessed by comparing the results of the measurements taken with the theodolite. Both the accuracy and precision must be within ±1 m.

1.8.2 Assessment of Angle Measurement

The angle measurement calibration test is performed by placing two mirrors approximately 180° apart. The theodolite is set up in the middle of the imaginary circle formed by the two mirrors. The angles of the two segments of the circle are measured. The sum of the two measurements should be close to 360°. This test is performed at least three times, and the results of the measurements are recorded in a laboratory notebook maintained by the Field Team Leader. The accuracy of the measurements is assessed by comparing the sum of the angles measured with the theodolite to 360°. The precision of the measurements is assessed by comparing the results of the three measurements. Both the accuracy and precision must be within ±2º.

1.9 Lowrance GPS

The accuracy of the GPS is built into the satellite system itself. The GPS will not provide a readout unless signals from a sufficient number of satellites have been received, allowing for calculation of a valid location.

The only pre-deployment check performed is to turn on the instrument and make sure it responds. In addition, ensure there are spare AA batteries. There is no need for a DQI test.

2.0 REFERENCES

a. U.S. Environmental Protection Agency, *Compendium Method TO-16: Long-Path Open-Path Fourier Transform Infrared Monitoring of Atmospheric Gases,* prepared under Contract No. 68-C3-0315, WA No. 3-10, Center for Environmental Research Information-Office of Research and Development, US EPA, Cincinnati, Ohio, Jan. 1999.

b. *American Society for Testing and Materials (ASTM) Standard Practice E1982-98, Standard Practice for Open-Path Fourier Transform Infrared (OP/FT-IR) Monitoring of Gases and Vapors in Air,* March, 1999.

c. Thoma, E. D.; Shores, R. C.; Thompson, E. L.; Harris, D. B.; Thorneloe, S. A.; Varma, R. M.; Hashmonay, R. A.; Modrak, M. T.; Natschke, D. F.; Gamble, H.A. Open Path Tunable Diode Laser Absorption Spectroscopy for Acquisition of Fugitive Emission Flux Data. *J. Air and Waste Manage Assoc*., **In Press**.